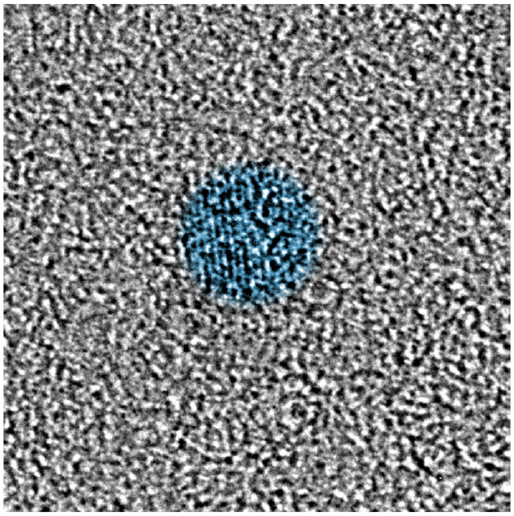
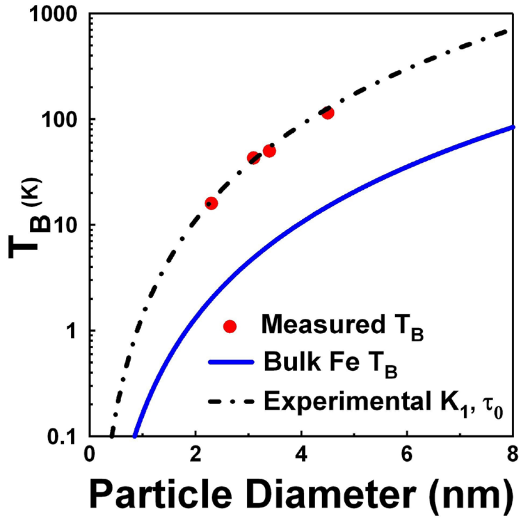
Tuning the Properties of Magnetic Nanoparticles Through Surfactant Design

Figure 1: (Left) A transmission electron micrograph of a single 3 nm iron nanoparticle (colorized for enhanced visibility), with no detectible oxide, and complete lattice fringes demonstrating the single crystal nature of the particle.

Figure 2: (Right) Plot of the measured blocking temperature for a series of different sizes of iron nanoparticles, fitted by an Arrhenius function (dash-dotted line) using the measured magnetic anisotropy (K1) for the nanoparticles. A curve of the values expected for bulk iron is shown in solid blue.





The control of magnetic properties of nanoparticles has been a long-time goal for science and industry

For more information:

Technical Contact:
Dale Huber
505-844-9194
dlhuber@sandia.gov

Science Matters Contact:
Alan Burns
505-844-9642
aburns@sandia.gov

Magnetic phenomena on the nanoscale are of growing interest for both scientific and technological reasons. For example, much of our modern information storage is based upon magnetism, and there is a continuous need for higher density storage and therefore smaller structures. The basics of nanomagnetism have been understood for decades for simple, well-behaved systems. Unfortunately, the only nanomagnets that behave well are those that are isolated both from each other and from a strongly interacting matrix material. Classical examples are particles suspended in a vacuum or inert carrier gas. For technological applications, it is critical for nanomaterials to be imbedded in some matrix material that will invariably alter their magnetic properties. Sandia's goal in this research is to understand, at a fundamental scientific level, how these matrix interactions alter the magnetism of nanoparticles. This fundamental knowledge will then enable the use of these materials in a variety of important technologies.

Since surfactants are a critical component in the nanoparticle synthesis, Sandia is examining how the choice of surfactants modifies the magnetic properties of nanoparticles. A system of un-oxidized iron nanoparticles was chosen as a model because of two important properties: it is both highly magnetic and extremely reactive. Thus the effect of chemical interactions between the surfactants and the nanoparticle surfaces should be easily detected.

A recently developed synthesis that utilizes beta-diketone-based surfactants has been shown to produce oxide-free, single crystal, iron nanoparticles (see Figure 1). These nanoparticles have a much higher effective magnetic anisotropy than would be expected for bulk iron, making them much "harder" magnets. Data that demonstrate this are shown in Figure 2, where the blocking temperatures of a series of iron particles of varying diameter are plotted. (The blocking temperature is the temperature below which magnetic nanoparticles behave as permanent magnets, and above which their magnetic moment freely reorients.) Based on a calculation using the bulk properties of iron, the expected blocking temperature is below 1K for the smallest particles shown. However, the data indicates that for all the particles tested, the blocking temperature is more than ten times the value predicted.

In contrast, performing the same synthesis using a more conventional polyether-based surfactant produces particles with bulk-like magnetic properties. Thus, by merely changing the organic matrix surrounding an iron nanoparticle, the magnetic hardness of the material can be altered by more than an order of magnitude. It appears that the extremely high anisotropy is a material property induced by the beta-diketone surfactant used. This hypothesis has been confirmed to the extent that unusual crystalline structure in these particles has observed with high energy X-ray diffraction. Developing an atomic level model of the structure of these particles and understanding how to systematically control it is the subject of ongoing research.

Because of the immense technological benefits, the control of the structure and magnetic properties of nanoparticles has long been a goal of materials science. For example, 2-5 nm magnetic particles could be used as bits for information storage if they are magnetically hard enough (have a high enough anisotropy). On the other hand, highly-efficient magnetic refrigeration requires lower anisotropy to maximize the magnetocaloric effect. Thus tuning the properties of the finite number of magnetic materials by varying surfactants could provide many new useful materials. This work is a step in that direction as Sandia has taken a famously soft magnetic material and made it a hard magnet.

Sandia National Laboratories

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000. SAND2009-1131P

National Nuclear Security Administration

02/2009